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A STRESS TEST TO EVALUATE THE PHYSICAL CAPACITY OF PERFORMING L-1 ANTI-G STRAINING MANEUVERS

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NOTICES

TECHNICAL REVIEW AND APPROVAL

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The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

James W. Brinkley

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To evaluate the physical capacity of performing L-1 anti-G straining maneuvers (AGSM), 9 subjects participated in stress test protocols which were designed to use repetitive AGSM exercise on the ground. Physiological responses of oxygen uptake (VO_2), minute pulmonary ventilation (VE), respiratory exchange ratio (RER) and heart rate (HR) were determined for steady state exercise at AGSM duty cycles of 20%, 25%, 33% and 50%. These exercise loads consisted of repeated 5-second L-1 AGSM maneuvers and were each followed by a 20, 15, 10, 5-second rest period, respectively. A total of 36 min progressive intensity (with respect to duty cycle), discontinuous protocols were used where exercise at each duty cycle was 4 min in duration followed by a 5 min rest interval. Physiological responses were found to be fairly linear in relationship to duty cycles. Another total 8 min progressive intensity, continuous protocol with 2 min exercise at each duty cycle, but no rest interval, was also tested. Since the continuous protocol takes less time and the results from both protocols show no significant difference (p 0.05), it is reasonable to choose a continuous

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protocol instead of a discontinuous one. All nine subjects repeated the continuous protocol and no significant differences ($p \angle 0.05$) were found between the test and retest for any peak values of the monitored physiological variables at 50% duty cycle. This AGSM continuous protocol was found to be reliable. Individual's endurance time of AGSM performance was defined by the self-exerted exercise duration at 50% duty cycle of continuous protocol until the VO_2 dropped 40% of his peak value. The individual's physical capacity for performing AGSM can be objectively evaluated by the strength (peak output) and endurance (time to 40% fatigue) aspects of this continuous stress test. The higher peak VO_2 achieved, the greater was considered the aerobic energy output for AGSM performance. This is dependent upon the muscle mass available, the condition of the muscles, as well as cardiopulmonary fitness of the individual. The longer endurance time for the ground test, the longer tolerance duration will most likely be obtained during actual centrifuge G-force testing. Therefore, the described AGSM stress test on the ground may be a convenient, inexpensive and useful tool to objectively evaluate the physical capacity of individuals for performing AGSM. Such a test may be used for pilot candidate screening prior to centrifuge and aircraft G-tolerance testing. Future studies need to correlate results of this ground test with centrifuge G-force tolerance.

PREFACE

This study was supported by the Laboratory Director's Fund of the Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433-6573. The utilization of humans for this project was authorized by the Air Force Human Use Committee (AAMRL Protocol 88-03), and by the Institutional Review Board Committee at Wright State University (Protocol HSP#704). This report is a dissertation submitted to Wright State University in partial fulfillment of the requirements for the degree of Master of Science in Aerospace Medicine.

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I. INTRODUCTION

Today's high performance aircraft with high thrust-to-weight ratios and low wing loading are more maneuverable than ever before. They are capable of maintaining +Gz acceleration longer and at higher levels (1,2,7). Under this condition, physiological tolerances of humans to acceleration can be easily exceeded, resulting in G-induced loss of consciousness due to insufficient cerebral blood flow (13,14,15). In order to protect the pilot against the effects of +Gz acceleration, several protective techniques and devices have been developed. These include L-1/M-1 anti-G straining maneuver (AGSM), positive pressure breathing, anti-G suit, reclined seat, etc. The L-1 AGSM is one of the major protective techniques which, when properly performed, provides approximately 2 +Gz additional physiological protection as compared to the relaxed condition with or without an anti-G suit (8). The L-1 AGSM consists of coordinated vigorous muscular tension of the abdomen and the extremities combined with simultaneously applied forced expiratory thrust upon the completely closed glottis. It is believed that maximized isometric contraction and intrathoracic pressure during the straining maneuver directly contribute to its greatest G-protection (26,27). However, frequent repetition of the AGSM, as required during actual aerial combat maneuvers (ACMs), can lead to a pilot's exhaustion and limit his AGSM performance (5,6). Thus, both strength and endurance for performing this maneuver are crucial for a pilot's success in operational ACMs.

There is much evidence to indicate a regime of weight training will lead to an increase in G-tolerance as determined by centrifuge testing (17-24). The assumption of these studies is that resistance-type exercise training can enhance the strength and endurance of muscular contraction in performing AGSM, which thus increases the G-tolerance level and duration. However, no published study actually uses direct measurement to assess the effects of physical training on the capacity for performing AGSM at 1 +Gz. Also, there is no published study estimating the direct effect of AGSM performance at 1 +Gz on actual G-tolerance. In order to quantify these effects, a laboratory test that can objectively evaluate the physical capacity for performing AGSM is necessary. It would also be desirable to evaluate if improvements in AGSM performance actually increase +Gz tolerance on the centrifuge.

It has also been suggested that measurement of various physiological indices of exercise in order to evaluate an individual's capacity for executing the fatiguing straining maneuvers be used as a selection procedure for high-performance aircraft pilots (23). Therefore, it would be very useful to develop a simple exercise stress test to predict +Gz tolerance of pilots based upon their physical capacity for performing the AGSM. Although there are many widely accepted protocols for physical evaluation using treadmill, bicycle ergometer, arm crank, rowing, swimming, and other exercise tasks, there is no available protocol that can be used for AGSM exercise testing.

In order to apply the concept of exercise specificity (21), a graded exercise stress test using the actual AGSM needs to be designed and validated for pilot evaluation.

The purpose of this study was to develop a valid and reliable exercise stress test protocol using the L-1 AGSM in order to objectively evaluate and classify individuals' capability for performing the AGSM. The results of such a test may be applicable for the selection of high-performance aircraft pilots who can tolerate high operational G-force.

II. METHODS

1. Subjects

Nine healthy subjects (eight males and one female) from the sustained acceleration stress panel at Wright-Patterson Air Force Base volunteered to participate in this study. All of the them have experience performing L-1 maneuvers. The physical characteristics ($\bar{X} \pm SD$) of the subjects were: age, 27.7 ± 3.4 years; height, 172.6 ± 9.2 cm; and weight, 72.4 ± 16.0 kg (Table 1; raw data in Appendix A). Each subject was informed as to the purpose of the study, their extent of involvement, any known risks, and their right to terminate participation at will. Each expressed understanding by signing a statement of informed consent. The protocols and procedures used for this study have been approved by the Institutional Review Board (IRB) of Wright State University, and the Human Use Review Committee of Armstrong Aerospace Medical Research Laboratory.

TABLE 1

ANTHROPOMETRIC CHARACTERISTICS OF THE SUBJECT POPULATION (n=9)

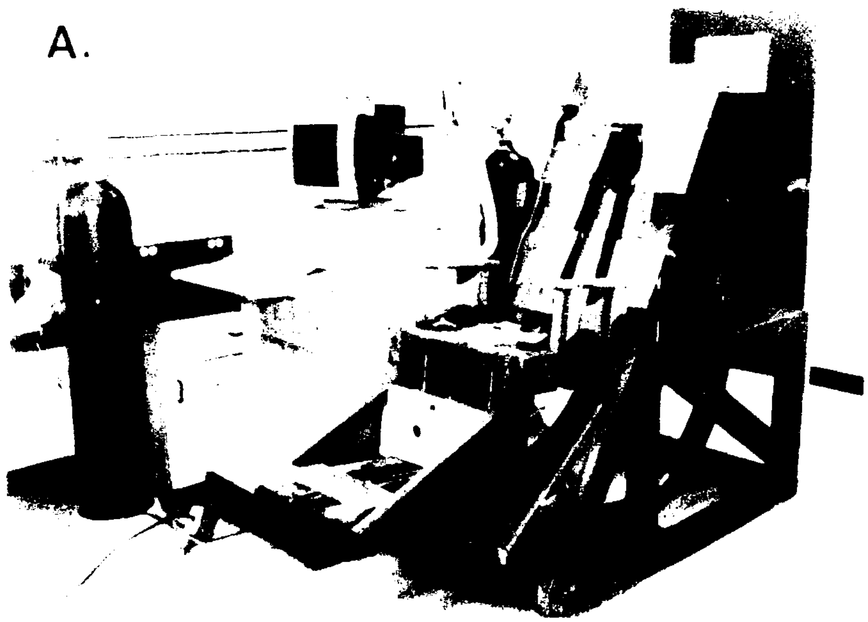
VARIABLE	MEAN	SD	MIN	MAX
AGE (years)	27.7	3.4	24	34
HEIGHT (cm)	172.6	9.2	162.6	188.0
WEIGHT (kg)	72.4	16.0	55.4	99.8
BSA (sqm)	1.85	0.24	1.62	2.26
SVC (l)	5.14	0.87	3.67	6.40
IC (l)	3.44	0.84	2.07	4.74
FVC (l)	4.86	0.74	3.96	6.07
FEV1 (l/sec)	3.98	0.60	3.31	5.17
MVV (l/min)	160.23	29.06	114.94	206.96

2. L-1 AGSM Stress Test Design

A "pilot's seat" used in another experiment (23) was adjusted to a seat back angle of 30 degrees, spine-to-thigh angle of 105 degrees and thigh-to-calf angle of 105 degrees in order to simulate the F-16 seat (Figure 1). Subjects were seated in the chair with their backs against the seatback and restrained in this fixed position by a lap belt. They were also instructed not to generate any external net force with their legs during the L-1 maneuver.

AGSM stress testing, hereafter also called exercise, consisted of repetitive performance of the L-1 maneuvers with progressively increasing duty cycle (ratio of the duration of L-1 maneuver to L-1

A.



B.

Figure 1. A: Experimental set-up of "Pilot's Seat" and metabolic cart.

B: Scene of AGSM stress test.

maneuver plus rest) to increase exercise intensity. Four different duty cycles, analogous to incremental exercise load levels, were established as: 20%, 25%, 33% and 50%. Thus, to perform these duty cycles, a 5-second maximal effort L-1 maneuver was followed by rest periods of either 20, 15, 10, 5 seconds, respectively.

There were two stress test protocols in this study: 1) The progressive intensity, discontinuous protocol (Figure 2) included 5 minutes of rest before exercise, 4 minutes of exercise at each duty cycle of 20%, 25%, 33% and 50% with 5 minutes rest intervals between subsequent intensity levels, and another 5 minutes of rest after exercise terminated to evaluate recovery patterns. 2) The progressive intensity, continuous protocol (Figure 3) included 5 minutes of rest before exercise, 2 minutes of exercise at each duty cycle of 20%, 25%, 33% and 50% without rest interval (the final 50% duty cycle lasted until subject fatigued or when $\dot{V}O_2$ dropped 40% below its peak value at 50% of duty cycle), and another 5 minutes of rest after exercise to evaluate recovery patterns. The exercise duration spent above 60% of one's peak oxygen uptake at 50% duty cycle of continuous protocols was counted as his endurance time.

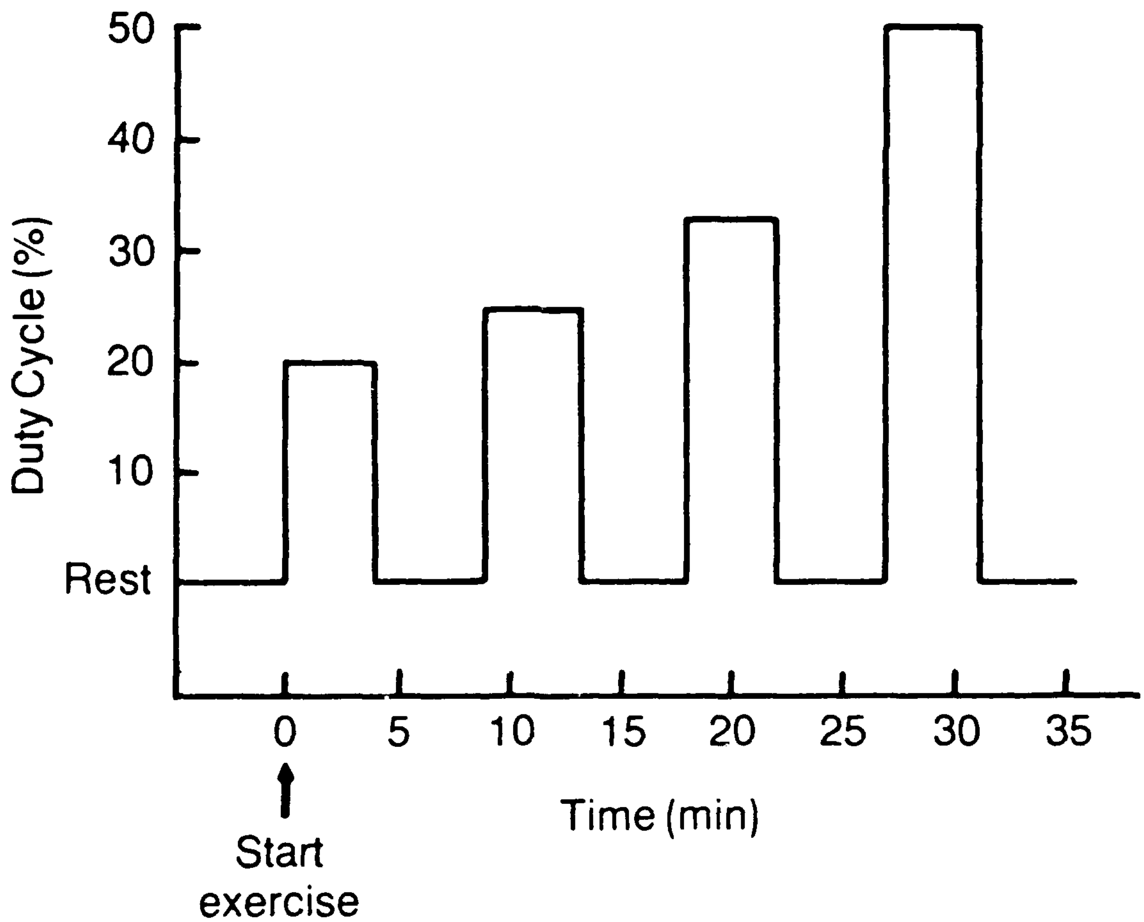


Figure 2. Discontinuous AGSM stress test protocol

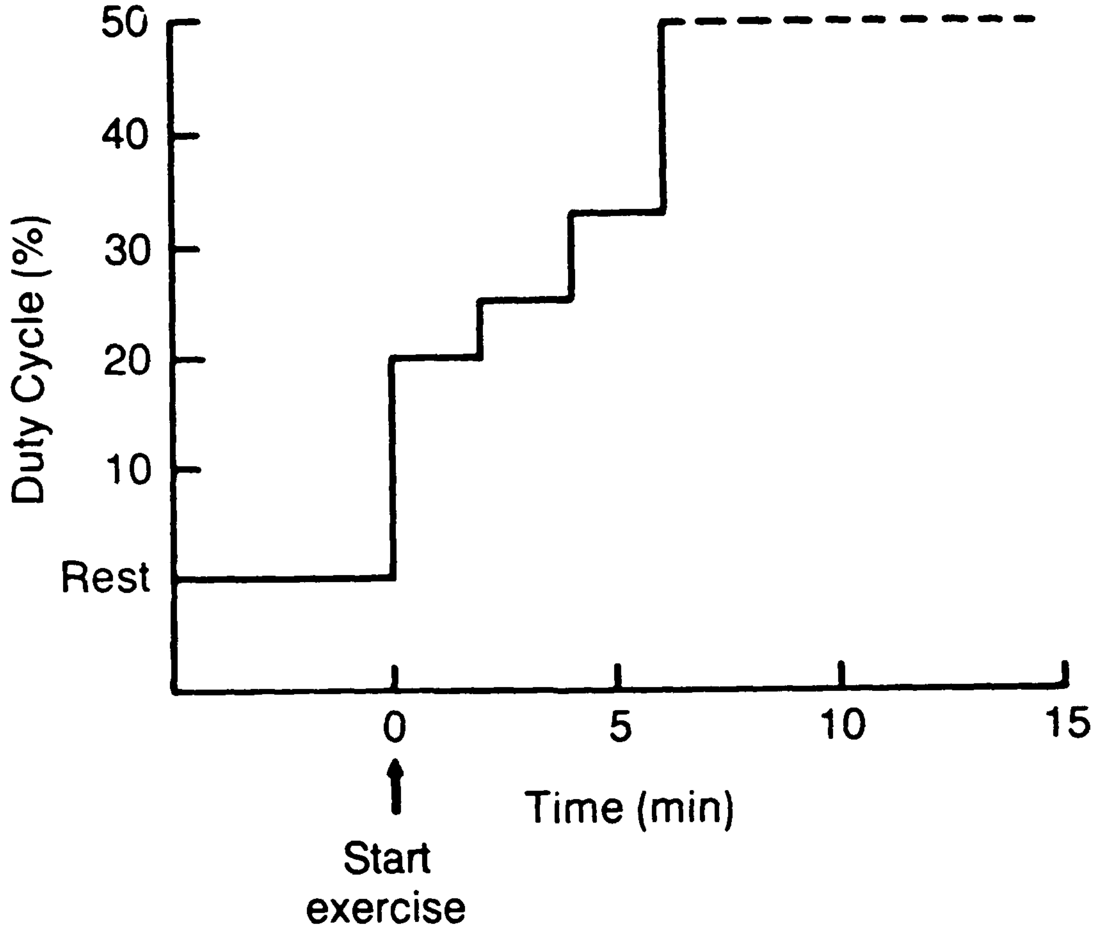


Figure 3. Continuous AGSM stress test protocol

3. Physiological Monitoring

Peak values of oxygen uptake ($\dot{V}O2$, ml/kg/min), minute pulmonary ventilation ($\dot{V}E$, l/min) and respiratory exchange ratio (RER, $\dot{V}CO_2/\dot{V}O_2$) at each duty cycle of discontinuous AGSM stress test and at 50% duty cycle of continuous AGSM stress test were calculated by automated open-circuit spirometry (Metabolic Cart, System 2001, Medical Graphics Corp., St. Paul, MN) during the stress tests. Pulmonary function testing (Table 1), including slow vital capacity (SVC), inspiratory capacity (IC), forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), maximal voluntary ventilation (MVV), was performed with System 1070 of the same instrument. Lactate concentration in capillary blood (LA, mmol/l) was determined at rest and three minutes following maximal exercise from a fingertip blood sample (model 23L lactate analyzer, Yellow Springs Instrument Co. Inc., Yellow Springs, OH). Bipolar surface electrodes were attached on the sternum area and the left 5th intercostal space for monitoring the heart rate.

4. Experimental Procedures

On a separate day prior to experimental testing, all subjects were familiarized with the testing procedures and the instrumentation for physiological determinations. Pulmonary function and general resting data were obtained. Each subject was observed by the investigator for correct performance of the L-1 maneuvers before actual testing was conducted. All subjects were instructed not to engage in strenuous physical activity before each testing day. On the morning of testing days, resting cardiopulmonary data were obtained after each subject remained seated quietly in the "pilot's seat" for 5 minutes. These determinations were continuously monitored during the entire stress test with the subjects breathing through a mouthpiece and a breathing valve which directed expired gases to the metabolic cart. EKG electrodes were placed on the chest for heart rate determination. The investigator always encouraged the subject to exert maximal effort during the L-1 maneuvers. Exercise was terminated by either fatigue or any condition which indicated high risk to the subject. Blood lactate concentration was determined at 1 minute before the start of exercise and 3 minutes after the end of 50% duty cycle exercise in both protocols. The discontinuous and continuous exercise protocols were performed on separate days. The continuous exercise stress test protocol was repeated at least 3 days after the previous continuous test to determine test-retest reliability.

5. Statistical Analysis

Standard statistical analyses including means, standard deviations, paired *t* tests and correlation coefficients were calculated using a programmable calculator (Texas Instruments TI-55 III). Statistical significance was chosen at 5% level.

III. RESULTS

All subjects completed the AGSM stress tests without any particular discomfort other than sweating, exhaustion and fatigue. There were no adverse effects following any of these AGSM stress tests. Subjects indicated that they preferred the continuous protocol to the discontinuous one because of the shorter exercise duration.

Figures 4-7 respectively present the steady-state $\dot{V}O_2$, $\dot{V}E$, RER and HR responses at rest and during the discontinuous AGSM stress test at 20%, 25%, 33% and 50% duty cycles (raw data in Appendix B). All of these physiological variables were found to increase in an approximately linear fashion with respect to duty cycle which simulates increased exercise loads. The responses at 50% duty cycle was considered the peak that the subjects could achieve.

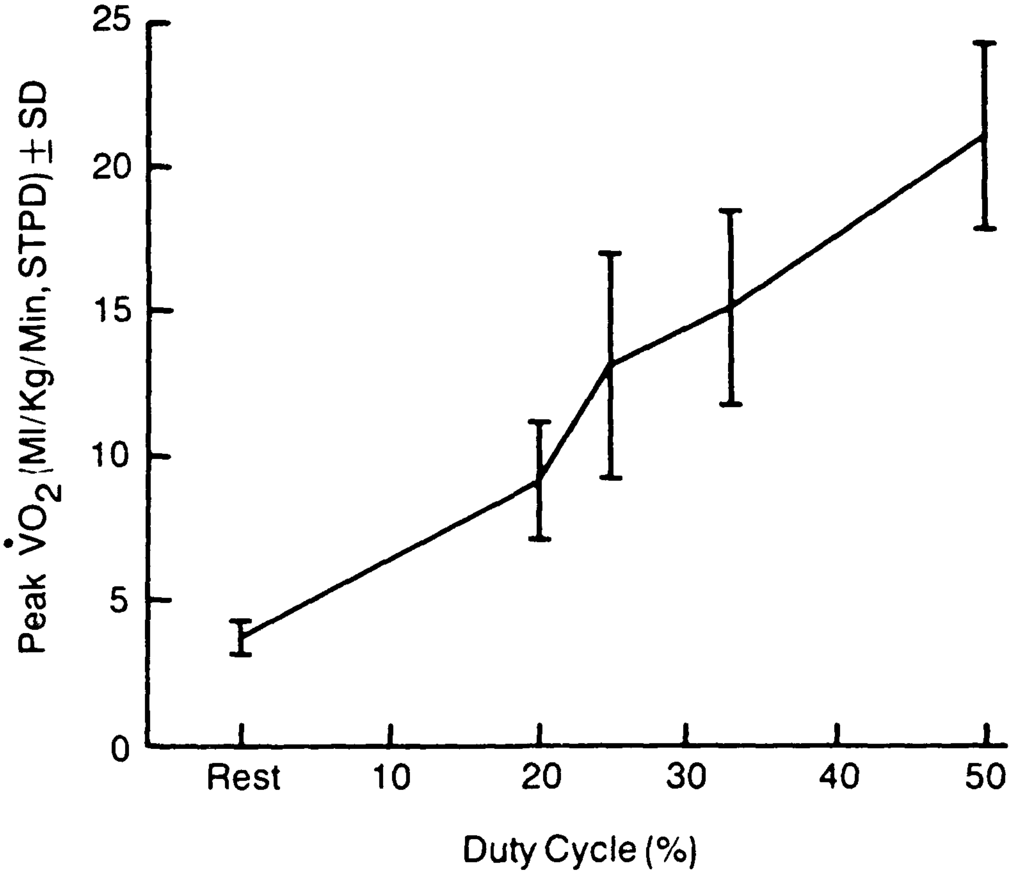


Figure 4. Relationship between the mean peak $\dot{V}O_2$ and duty cycle (n=9).

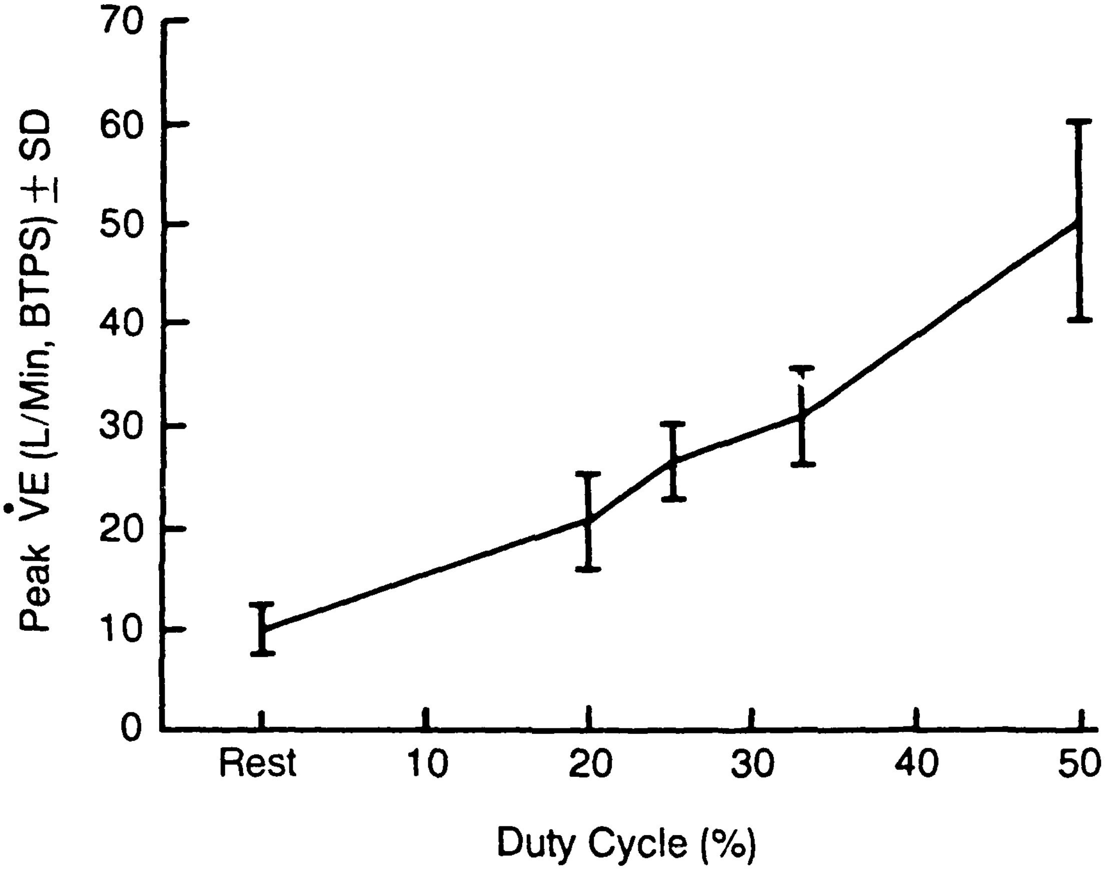


Figure 5. Relationship between the mean peak V̇E and duty cycle (n = 9).

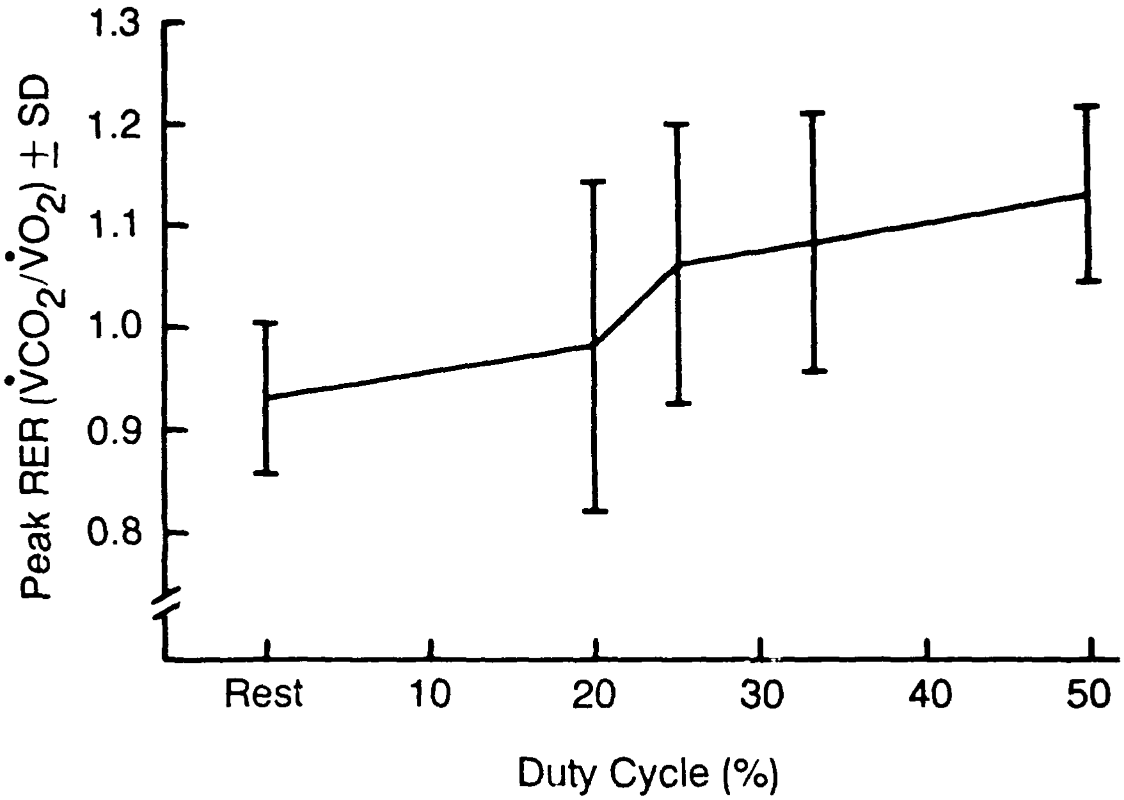


Figure 6. Relationship between the mean peak RER and duty cycle (n = 9).

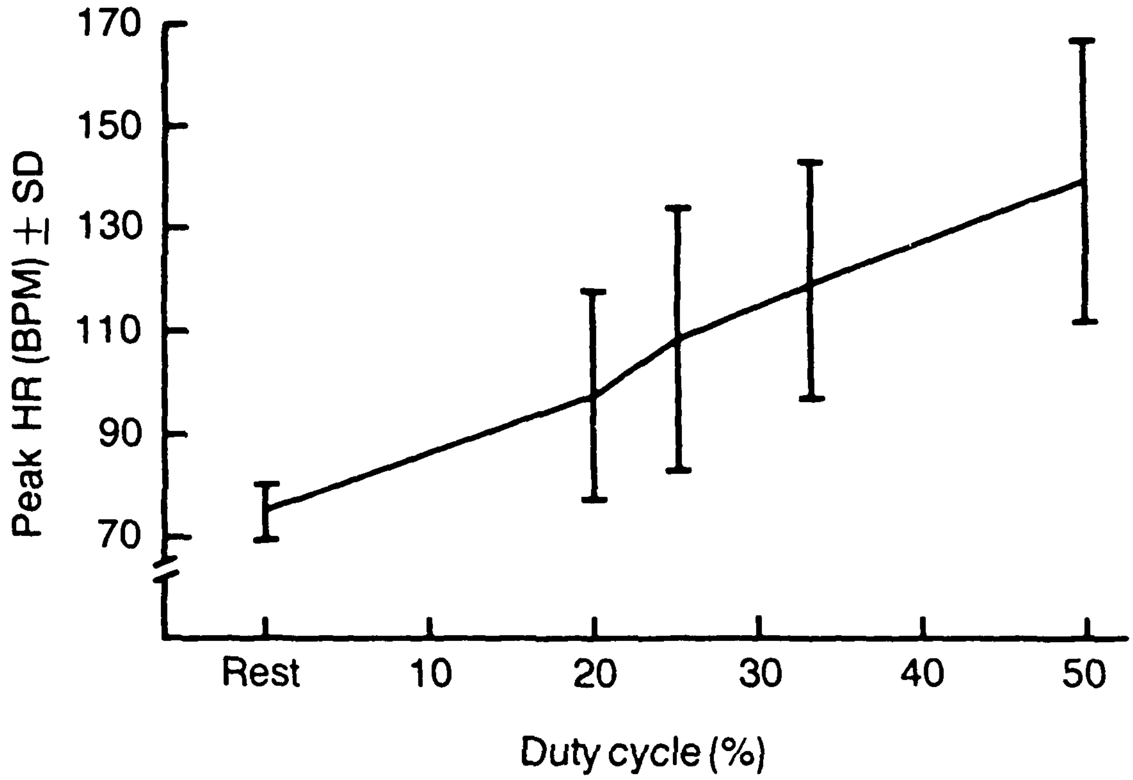


Figure 7. Relationship between the mean peak HR and duty cycle (n = 9).

Figures 8-13 present the comparison of the mean peak $\dot{V}O_2$, $\dot{V}E$, RER, HR, LA and endurance time at the 50% duty cycle level between the discontinuous and continuous (trials 1 & 2) stress test protocols. The means and standard deviations of those above physiological variables were shown in Table 2 (raw data in Appendix C). Table 3 presents the results of paired *t* tests between the means for each variable. It indicated that none of them was significantly different at the $p < 0.05$ level. Table 4 presents the correlation coefficients (r) for each physiological variable between the discontinuous and continuous (trials 1 & 2) AGSM stress test protocols. These correlation coefficients were significant at the $p < 0.05$ level.

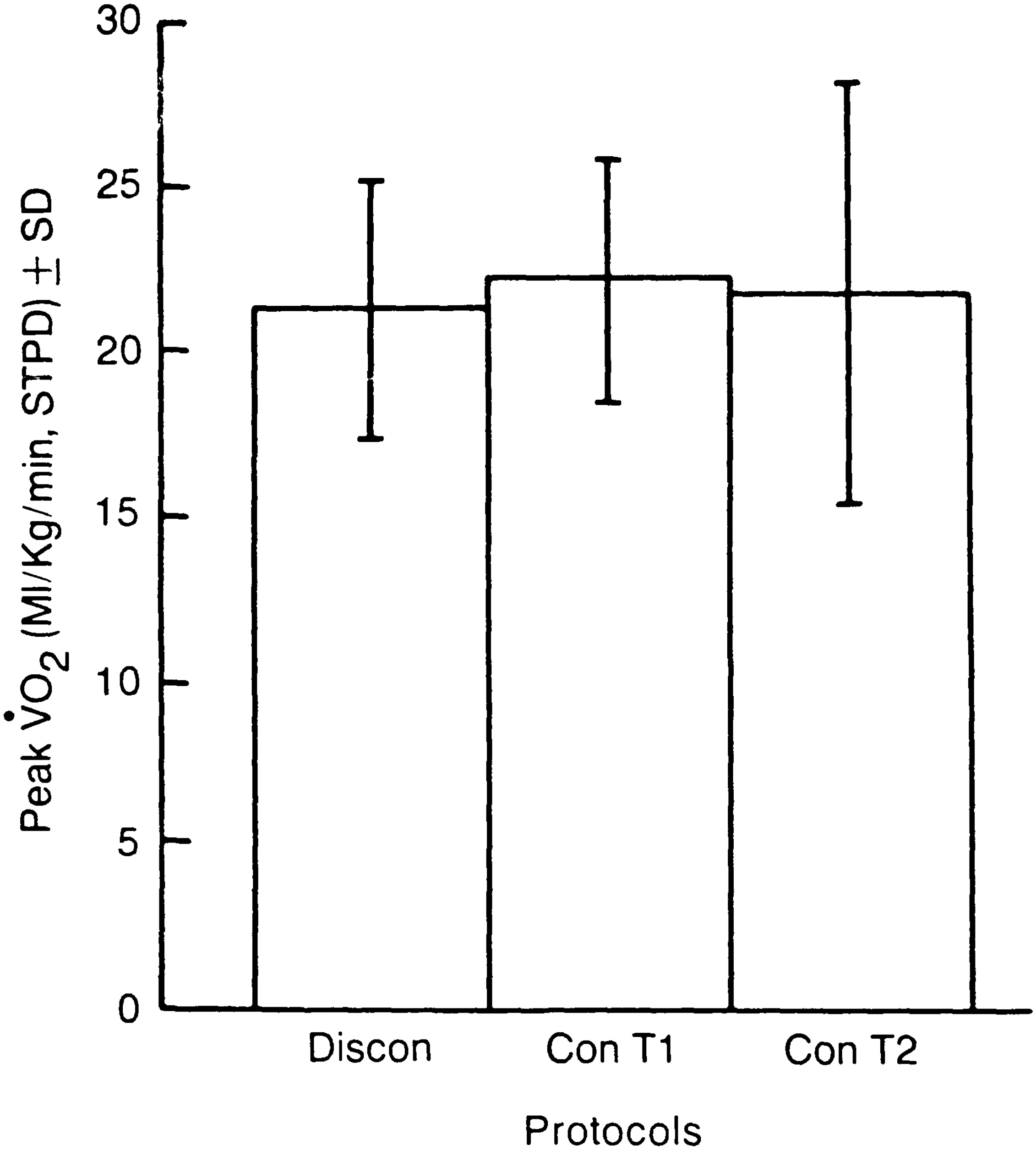


Figure 8. A comparison of mean peak $\dot{V}O_2$ at 50% duty cycle between the Discontinuous (Discon) and Continuous (Con, Trials 1 & 2) AGSM stress test protocols (n = 9).

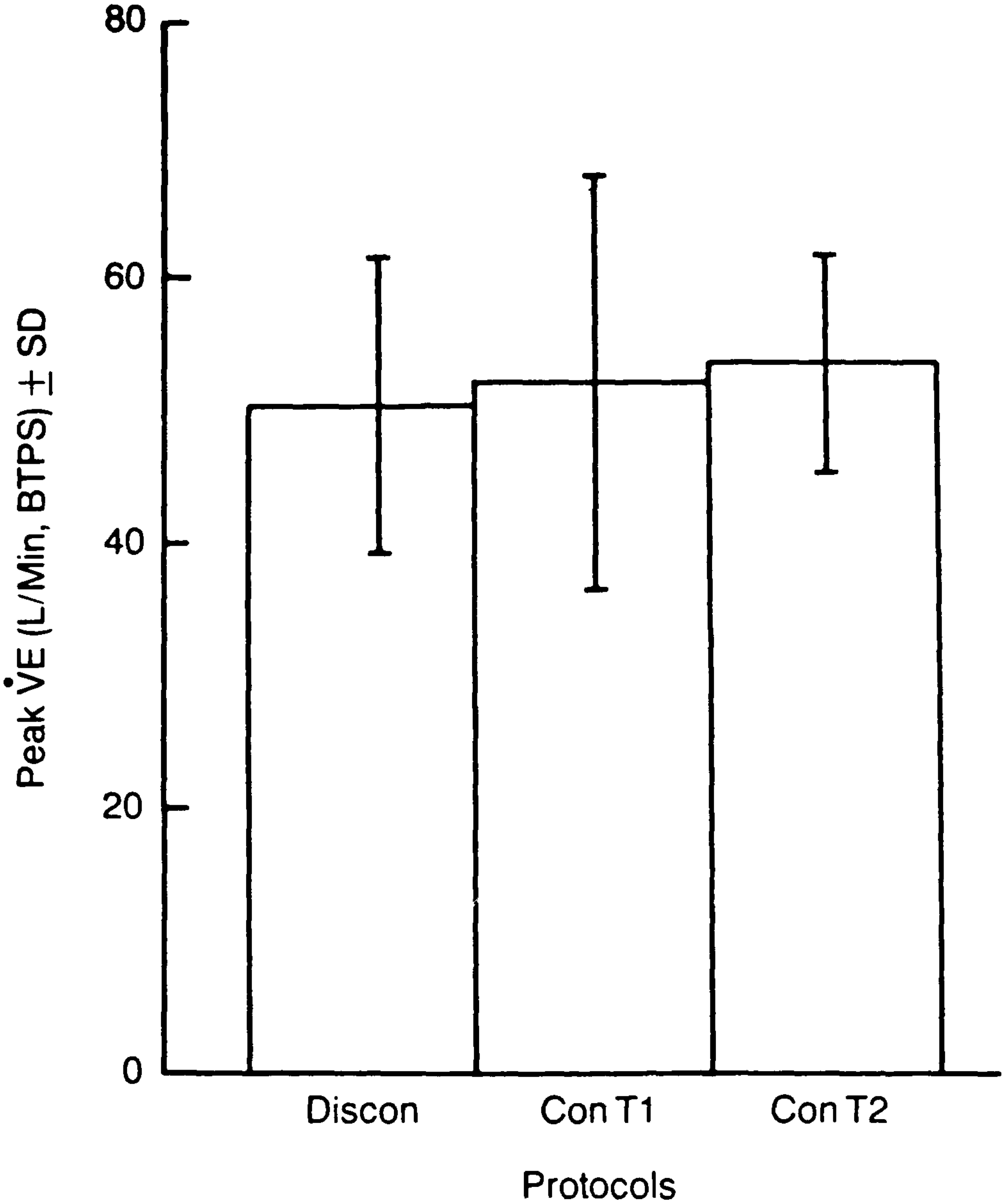


Figure 9. A comparison of mean peak V̇E at 50% duty cycle between the Discontinous (Discon) and Continuous (Con, Trials 1 & 2) AGSM stress test protocols (n = 9).

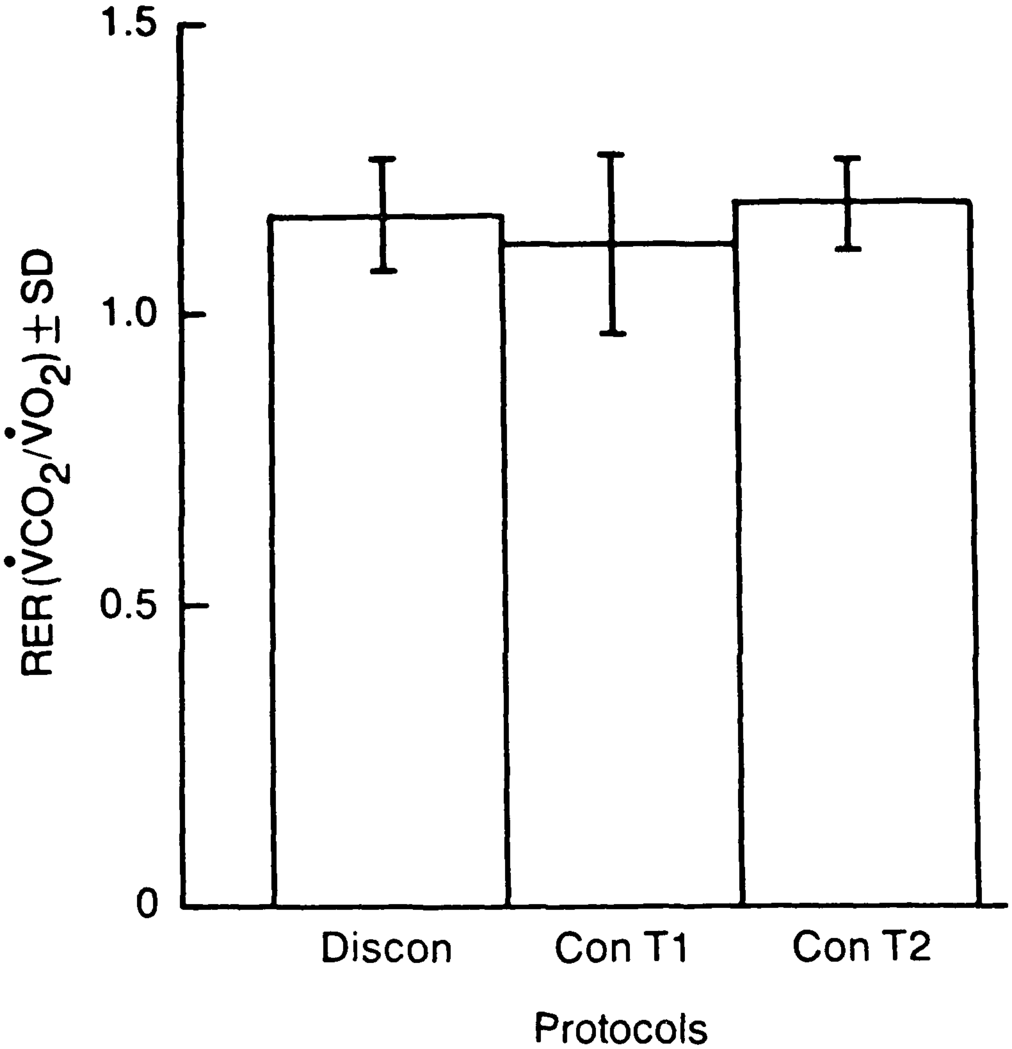


Figure 10. A comparison of mean peak RER at 50% duty cycle between the Discontinuous (Discon) and Continuous (Con, Trials 1 & 2) AGSM stress test protocols (n = 9).

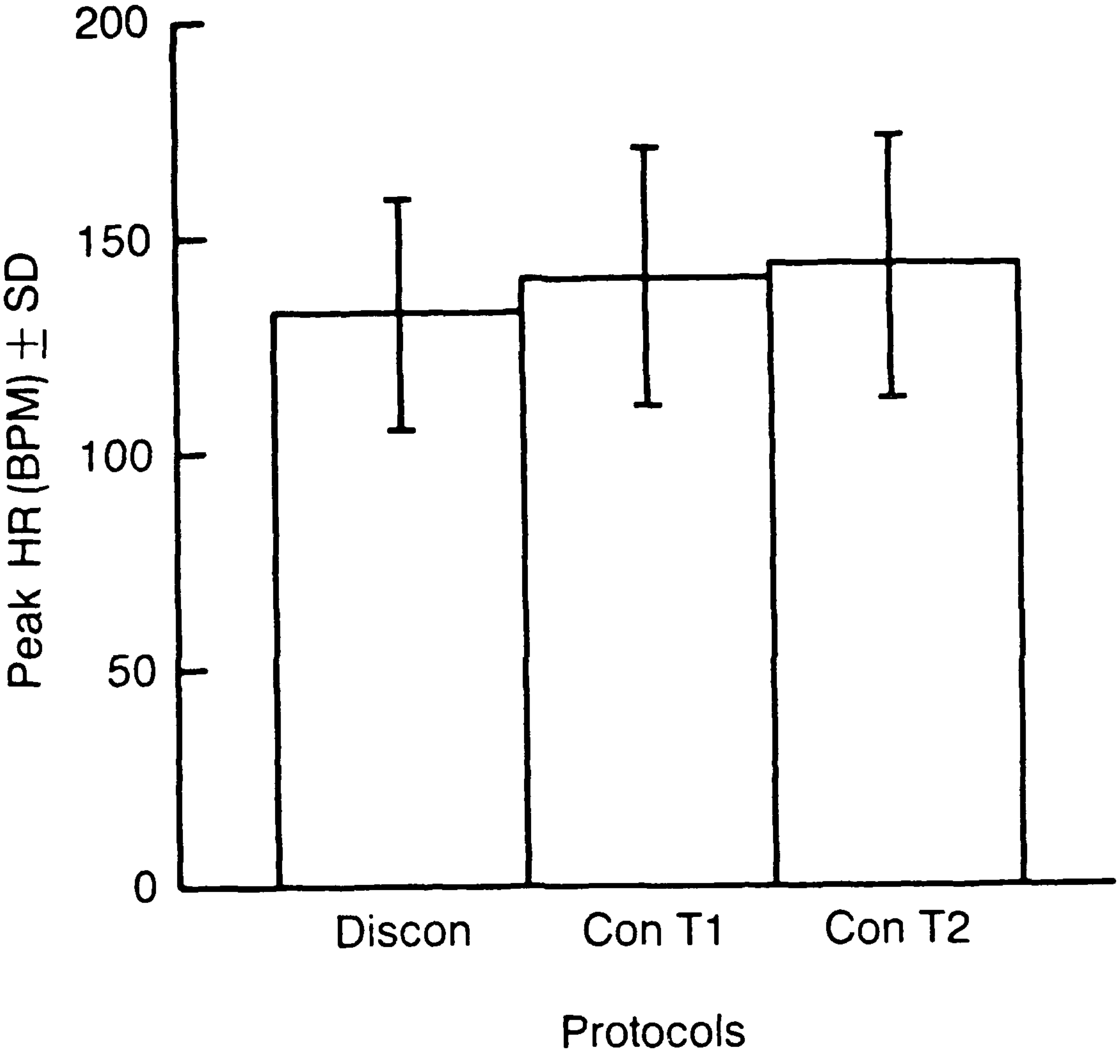


Figure 11. A comparison of mean peak HR at 50% duty cycle between the Discontinuous (Discon) and Continuous (Con,Trials 1 & 2) AGSM stress test protocols (n = 9).

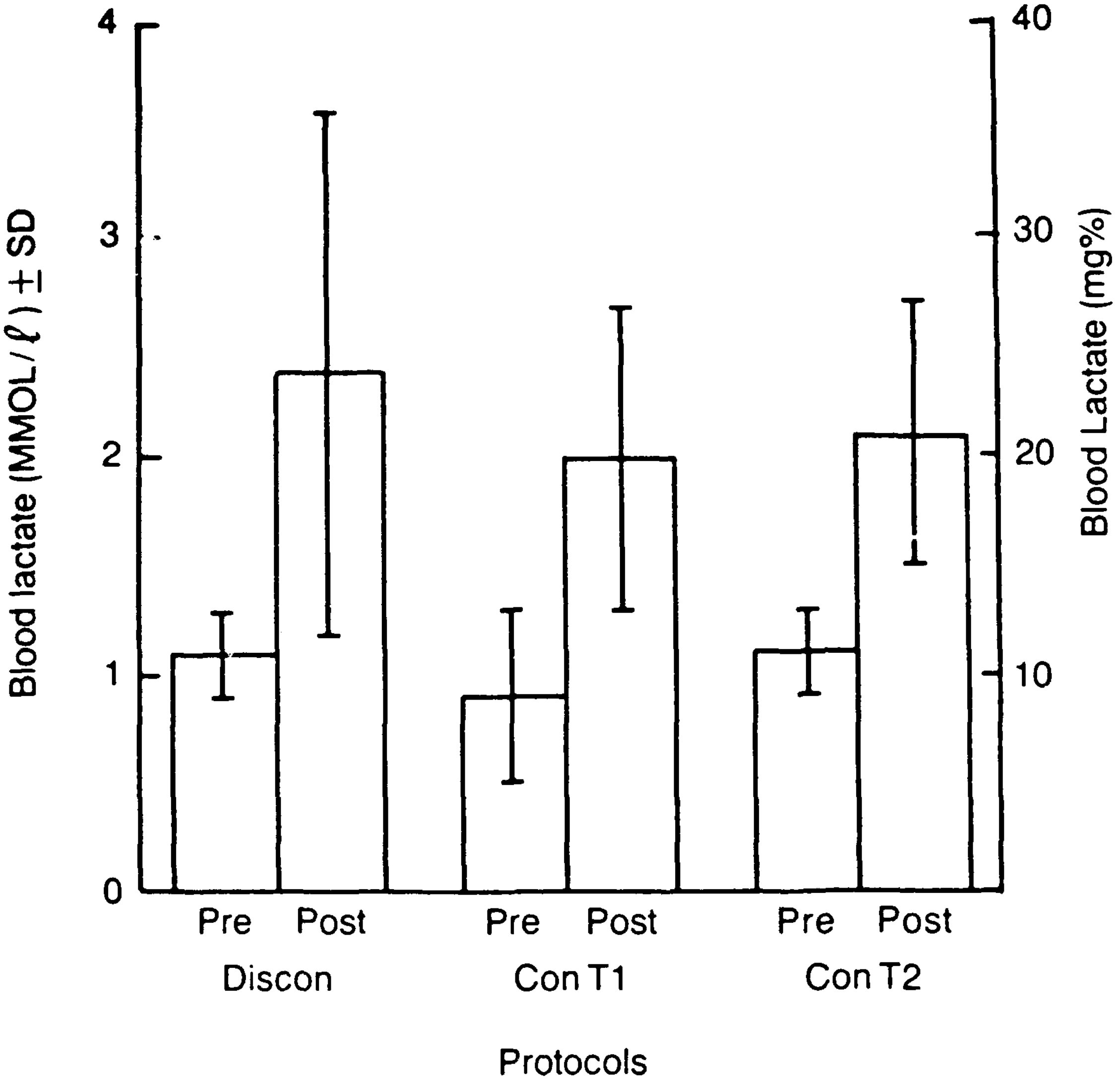


Figure 12. A comparison of Pre- and Post- exercise mean blood lactate levels between the Discontinuous (Discon) and Continuous (Con, Trials 1 & 2) AGSM stress test protocols. (n = 9).

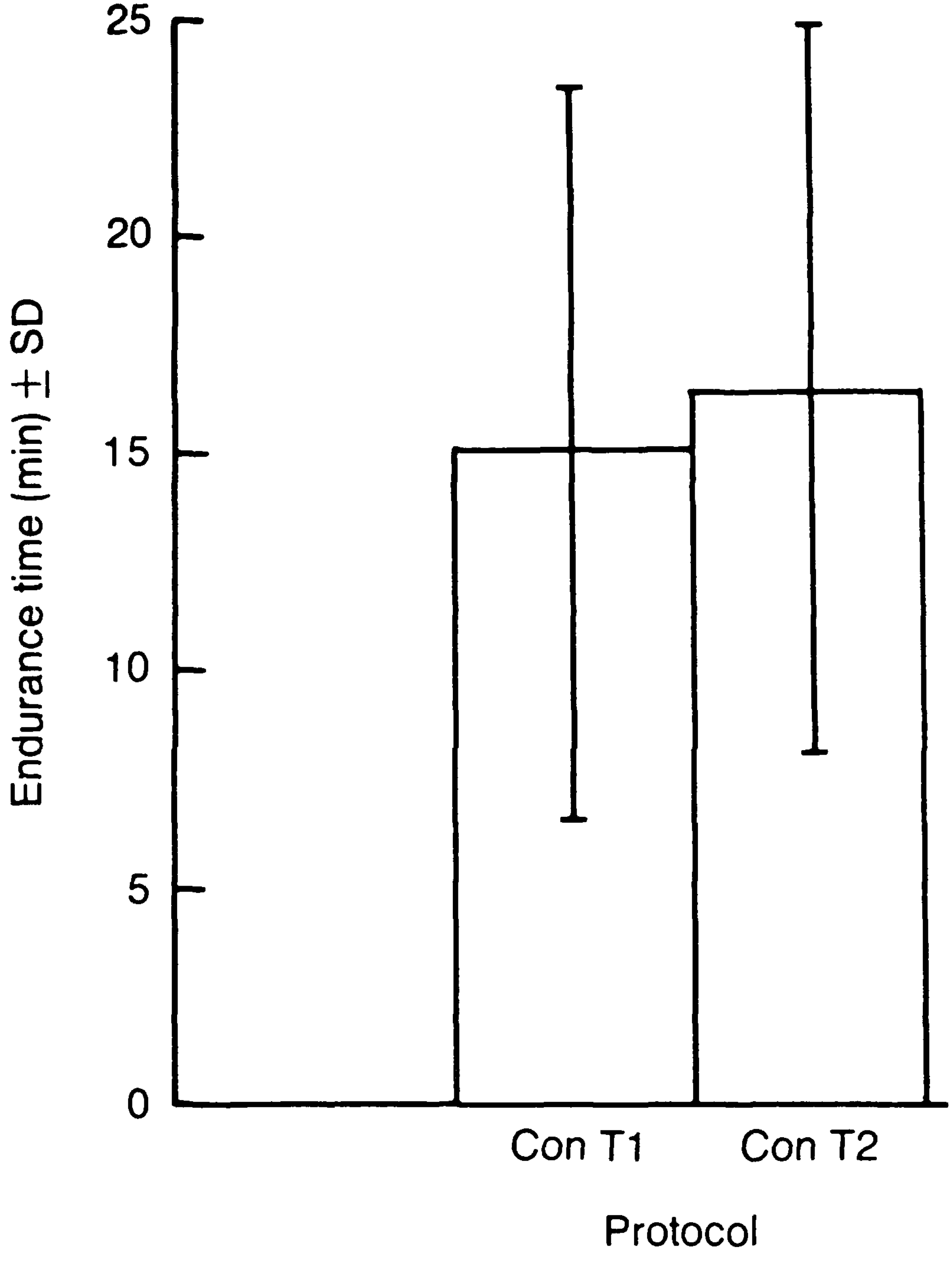


Figure 13. A comparison of mean endurance time at 50% duty cycle between Continuous AGSM stress test protocol Trial 1 and Trial 2 (n = 9).

TABLE 2

Means and standard deviations of peak oxygen uptake, minute pulmonary ventilation, respiratory exchange ratio, heart rate, post-exercise blood lactate and endurance time at 50% duty cycle in discontinuous (DISCON) and continuous (CON, Trials 1 & 2) ACSM stress tests.

Test Protocol	VO_2 (ml/kg/min) ($\bar{X} \pm SD$)	VE (l/min) ($\bar{X} \pm SD$)	RER (VCO_2/VO_2) ($\bar{X} \pm SD$)	HR (bpm) ($\bar{X} \pm SD$)	LA (mmol/l) ($\bar{X} \pm SD$)	ENDURANCE (minute) ($\bar{X} \pm SD$)
DISCON	21.3 ± 3.5	50.2 ± 13.0	1.17 ± 0.12	139.1 ± 30.2	2.4 ± 1.2	
CON T1	22.2 ± 3.5	51.9 ± 15.8	1.12 ± 0.17	140.8 ± 31.2	2.0 ± 0.7	15.1 ± 8.6
CON T2	21.8 ± 5.4	53.1 ± 8.9	1.19 ± 0.09	143.7 ± 31.2	2.1 ± 0.6	16.3 ± 8.8

TABLE 3

T values of paired *t* tests for each physiological variable between discontinuous (DISCON) and continuous (CON, Trials 1 & 2) AGSM stress tests.

	VO_2	VE	RER	HR	LA	ENDURANCE
DISCON vs CON T1	1.92	0.43	-1.16	0.26	-1.6	
DISCON vs CON T2	0.41	1.03	0.83	0.75	-0.73	
CON T1 vs CON T2	-0.33	0.31	1.68	0.53	1.43	1.19

Note: All values are not significantly different at 5% level.

TABLE 4

Correlation coefficients (r) for each physiological variable at 50% duty cycle between the discontinuous (DISCON) and continuous (CON, Trials 1 & 2) AGSM stress tests.

COMPARISON	$\dot{V}O_2$	$\dot{V}E$	RER	HR	LA	ENDURANCE
DISCON vs CON T1	0.92	0.70	0.66	0.80	0.87	
DISCON vs CON T2	0.73	0.77	0.81	0.82	0.75	
CON T1 vs CON T2	0.97	0.66	0.73	0.86	0.77	0.94

Note: All values are significant at 5% level.

IV. DISCUSSION

The AGSM stress test protocols devised in this study provided an exercise load that is similar to that which is actually encountered by fighter pilots both in centrifuge training and in-flight ACMs. Therefore, it appears that these tests can be used for objective evaluation of one's fitness and capacity of performing AGSMs. There is still a need to correlate the capability of performing AGSMs and actual G-tolerance. The duty cycles selected for this study were 20%, 25%, 33% and 50% which are repeated 5-second AGSM exercise bouts interrupted by 20, 15, 10 and 5 seconds rest period, respectively. It is universally agreed that the optimal L-I AGSM duration is 3-5 seconds including an expiratory thrust upon closed glottis and a quick respiration (2). However, a previous study showed that three AGSMs in succession, without interruption for a ground test, can produce peak mean arterial blood pressure averaging 195 mmHg (23). For safety reasons, it was decided not to use continuous AGSMs but to interrupt them with rest periods. For the discontinuous protocol, physiological data were collected during the fourth minute of each AGSM exercise duty cycle to obtain steady state values. The 5-min rest periods that followed bouts of exercise were used to allow time for recovery of the subjects. The physiological responses elicited by the various duty cycles indicated the ability to gradually increase the stress effects. This is analogous to the progressive increase in exercise intensity that is used for treadmill and bicycle ergometer stress testing. Thus, the described AGSM stress tests may be useful for objectively evaluating one's fitness for performing this activity.

Energy for most endurance exercise (more than a few minutes in duration) is derived from aerobic metabolism. Oxygen uptake reflects this energy utilization. The peak oxygen uptake indicates the peak rate that energy can be derived by aerobic metabolism. It is dependent upon the fitness of the active muscles and the capacities of the cardiovascular and pulmonary systems. In comparing individuals' physical capacity, absolute peak $\dot{V}O_2$ (l/min) is often expressed in relative terms (ml/kg/min) by dividing the absolute value by body weight. The higher the relative peak $\dot{V}O_2$ value, the greater is the quality of the person's body weight. Since AGSM is a kind of static exercise with isometric contractions, one may expect to obtain lower peak oxygen uptake value than can be obtained from treadmill or cycle ergometer stress testing. However, the peak oxygen uptake during the AGSM tests is still a good indicator of individual's physical capability for performing this activity.

It is difficult to precisely measure the subject's muscle contraction strength during AGSM performance. Fortunately, all our volunteer subjects came from the Air Force Acceleration Panel. Thus, they have had extensive experience for performing AGSMs. Since they are regularly performing these maneuvers, it was assumed that they were exerting their maximal effort for each maneuver as was directed by the investigator.

As indicated, the AGSM tests consisted of intermittent isometric exercise with alternating 5 seconds muscular contractions and 5 to 20

seconds of relaxation. In such a short duration, high intensity exercise, it is expected that there would be a substantial anaerobic energy component with a concommitant accumulation of lactate in the blood. Indeed, blood lactate concentration increased 2-2.5 times above the rest level after completion of the 50% AGSM duty cycle. Burton et al. (7) pointed out that the AGSMs performed during high-G centrifuge testing elicited blood lactate levels that were 200% higher than the AGSMs performed at 1-G control. This suggests that there may be considerably more anaerobic activity, independent of the AGSM, occurring during actual G loading.

Cote et al. (11) did a study analyzing the relationship between inspiratory volume and G-tolerance. He concluded that the inspiratory volume during performing of AGSMs positively relates to G-tolerance level. Rapid, small breaths similar to hyperventilation can produce respiratory alkalosis. Therefore, lowered G-tolerance may result from decreased cerebral blood flow. Another factor is that a large inspiratory volume can contribute to increasing the intrathoracic pressure which can help build up cerebral blood pressure. Finally, he suggested pilots take large breaths (about 85% maximal inspiratory volume) without excessively exerting themselves in order to achieve better G-tolerance. In the present study, subjects were instructed to take relatively large breaths.

None of the monitored physiological variables were significantly different between the discontinuous test and continuous test trial 1 or between the discontinuous test and continuous test trial 2. This indicates that it is possible to use the continuous test protocol instead of the discontinuous test protocol and elicit the same peak responses in a shorter time period. The test results from the continuous test protocol trial 1 and 2 were very consistent, although these tests were performed at least 3 days apart. This indicates that there is high test-retest reliability for the continuous AGSM stress test protocol.

Peak $\dot{V}O_2$ and endurance time attained during the continuous AGSM protocol provides information on the strength and endurance components of an individual's AGSM performance capability. These data can be classified and correlated to actual G-tolerance on the centrifuge in further studies. Based on the inter-individual variability of peak $\dot{V}O_2$ and endurance time during the AGSM test, these subjects exhibited a wide range of AGSM performance capability (Table 2). Since this is a voluntary exertion exercise, the consistency of maximal effort of every AGSM bout can be influenced by the individual's motivation, will to compete and stamina. Therefore, the magnitude of the peak $\dot{V}O_2$ and endurance time may not fully reflect the individual's capability for AGSM performance. However, fighter pilots, in general, may exhibit more stamina, they are highly competitive, and they may be more motivated for AGSM exercise tests. Therefore, when using actual pilots, results may be more valid.

Further study will incur the results of this experiment to validate the correlation between capability of AGSM performed at 1 +Gz and actual G-tolerance on centrifuge.

V. CONCLUSION

1. The proportional magnitudes of the physiological responses elicited at the various duty cycles indicated the ability to gradually increase the stress effects. Thus, the described AGSM stress tests may be useful for objectively evaluating the maximal energy output (including endurance) by individual for performing this activity.

2. No significant difference for any of the monitored physiological variables was found between the discontinuous AGSM stress test and the continuous AGSM stress test (trials 1 & 2). Therefore, the continuous AGSM stress test protocol which is a substantially shorter test can be used instead of the longer duration discontinuous AGSM stress test, and it can be expected that similar peak magnitudes of physiological responses will be obtained.

3. The high correlations for oxygen uptake and endurance value between trial 1 and trial 2 indicated high test-retest reliability for measuring physical capacity of performing AGSM.

4. The described AGSM stress test on the ground may be a convenient, inexpensive and useful tool for objectively evaluating the physical capacity of individuals for performing AGSM. Future studies need to correlate results of this ground test with centrifuge G-force tolerance to substantiate the validity of the AGSM stress test, and to better understand the limiting factors for G-force tolerance.

APPENDIX A

SUBJECT DESCRIPTIVE DATA (n=9)

SUBJECT	SEX	AGE (years)	HEIGHT (cm)	WEIGHT (kg)	BSA (sqm)	SVC (1)	IC (1)	FVC (1)	FEV1 (1/sec)	MVV (1/min)
1	M	26	165.3	68.0	1.75	5.22	3.82	4.85	4.18	171.49
2	M	26	165.0	59.2	1.65	5.36	3.35	4.78	4.01	184.15
3	M	32	168.1	55.4	1.62	4.76	2.44	4.57	3.62	159.60
4	M	25	177.8	80.3	1.98	5.18	3.18	4.90	3.69	114.94
5	M	34	177.8	90.3	2.11	4.79	4.25	4.22	3.44	140.33
6	M	27	188.0	99.8	2.26	6.37	4.74	6.04	5.17	179.71
7	M	29	165.7	60.8	1.67	4.49	3.27	4.35	3.73	156.85
8	M	24	182.9	76.2	1.98	6.40	3.80	6.07	4.63	206.96
9	F	26	162.6	59.0	1.63	3.67	2.07	3.96	3.31	128.05
$\bar{X}$		27.7	172.6	72.4	1.85	5.14	3.44	4.86	3.98	160.23
S.D.		3.4	9.2	16.0	0.24	0.87	0.84	0.74	0.60	29.06

APPENDIX B

DISCONTINUOUS AGSM STRESS TEST DATA

REST

SUBJECT	$\dot{V}O_2$ (ml/kg/min)	$\dot{V}E$ (l/min)	RER ($\dot{V}CO_2/\dot{V}O_2$)	HR (bpm)
1	4.2	9.2	0.96	69
2	4.2	8.5	0.90	73
3	4.1	7.3	0.81	74
4	4.1	11.3	0.90	71
5	4.0	10.3	0.90	87
6	3.8	14.7	0.88	74
7	3.3	11.3	1.05	83
8	3.7	11.1	1.06	70
9	2.4	7.5	0.91	76
$\bar{X}$	3.8	10.1	0.93	75.2
S.D.	0.6	2.3	0.08	6.0

20% DUTY CYCLE

SUBJECT	$\dot{V}O_2$	$\dot{V}E$	RER	HR
1	10.3	18.0	1.00	84
2	9.5	14.3	0.92	94
3	14.2	14.5	0.88	147
4	7.7	18.2	0.92	82
5	10.8	19.8	0.82	101
6	9.5	26.0	0.87	82
7	8.9	27.2	1.35	97
8	9.9	28.5	0.98	82
9	5.5	16.2	1.12	84
$\bar{X}$	9.6	20.3	0.98	94.8
S.D.	2.3	5.5	0.16	20.9

APPENDIX B
(Continued)

25% DUTY CYCLE

SUBJECT	$\dot{V}O_2$	$\dot{V}E$	RER	HR
1	14.6	23.7	1.08	113
2	14.0	24.3	1.06	119
3	20.4	23.1	0.97	174
4	12.9	27.2	0.96	96
5	14.9	27.7	0.92	117
6	12.2	29.0	0.89	95
7	12.6	32.7	1.29	98
8	11.0	30.4	1.12	87
9	5.5	19.0	1.26	91
$\bar{X}$	13.1	26.3	1.06	110
S.D.	3.9	4.2	0.14	26.7

33% DUTY CYCLE

SUBJECT	$\dot{V}O_2$	$\dot{V}E$	RER	HR
1	16.8	30.6	1.09	125
2	16.1	28.4	1.11	136
3	20.7	22.6	1.02	181
4	14.6	28.7	0.92	102
5	17.1	35.7	1.02	126
6	13.6	34.4	0.99	103
7	15.0	39.9	1.33	99
8	13.4	29.4	1.00	96
9	7.5	28.3	1.26	100
$\bar{X}$	15.0	30.9	1.08	118.7
S.D.	3.6	5.1	0.13	27.5

APPENDIX B
(Continued)

50% DUTY CYCLE

SUBJECT	$\dot{V}O_2$	$\dot{V}E$	RER	HR
1	24.8	66.7	1.27	154
2	24.1	60.3	1.17	153
3	24.1	25.5	1.17	194
4	23.9	51.1	0.97	151
5	23.7	65.7	1.16	155
6	18.6	44.2	1.02	115
7	18.1	44.9	1.20	108
8	15.8	42.1	1.13	98
9	18.6	51.7	1.08	124
$\bar{X}$	21.3	50.2	1.13	139.1
S.D.	3.5	13.0	0.09	30.2

APPENDIX C

Data of peak values for each physiological variable at 50% duty cycle in discontinuous (DISCON) and continuous (CON, Trials 1 & 2) AGSM stress tests

SUBJECT	VO_2 (ml/kg/min)			VE (l/min)			RER (VCO_2/VO_2)		
	DISCON	CON T1	CON T2	DISCON	CON T1	CON T2	DISCON	CON T1	CON T2
1	24.8	26.3	31.1	66.7	81.2	67.1	1.27	1.37	1.24
2	24.1	26.7	26.4	60.3	49.1	51.1	1.17	1.05	1.21
3	24.1	23.7	26.8	25.5	34.9	38.1	1.17	1.14	1.11
4	23.9	24.0	23.3	51.1	60.2	54.1	0.97	1.06	1.09
5	23.7	23.7	17.7	65.7	53.8	62.1	1.16	0.87	1.14
6	18.6	18.7	20.0	44.2	52.3	59.7	1.02	1.05	1.16
7	18.1	20.7	17.0	44.9	49.7	51.8	1.35	1.36	1.38
8	15.8	18.0	18.6	42.1	25.6	49.0	1.13	0.95	1.13
9	18.6	17.7	15.3	51.7	60.2	45.2	1.26	1.20	1.21

Appendix C
(continued)

Data of peak values for each physiological variable at 50% duty cycle in discontinuous (DISCON) and continuous (CON, Trials 1 & 2) AGSM stress tests

SUBJECT	HR (bpm)			LA (mmol/l)			ENDURANCE (min)	
	DISCON	CON T1	CON T2	DISCON	CON T1	CON T2	CON T1	CON T2
1	154	152	154	3.2	2.8	2.3	32	34
2	153	169	176	2.8	2.3	2.7	18	17
3	194	201	179	1.6	1.7	2.6	13	13
4	151	141	171	1.5	1.3	1.7	21	21
5	155	116	141	5.0	2.8	3.0	8	5
6	115	148	153	1.2	0.9	1.5	21	22
7	108	117	108	2.9	2.4	2.3	7	9
8	98	99	92	1.2	1.7	1.8	7	9
9	124	124	119	1.9	1.7	1.4	9	17

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